

STUDIES OF SOME ENERGY DOUBLER MAGNET PROPERTIES

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I. Introduction

A series of measurements was recently undertaken to check the long term stability of various magnet properties. Two magnets, in particular, were subjected to very detailed studies.

Magnet PCA148, measured at the MTF on Stand #1, was checked for long term stability of the magnetic plane as a function of quench history, as well as warmup-cooldown cycles. Repeated measurements on D.C. and A.C. harmonics were also done. There is no indication of any changes in the transfer ratio or in the harmonic components of the field after more than 130 quenches at high current (corresponding to about 1000 GeV or more).

Magnet RDA101 (Stand #2) was outfitted with a special relief line that showed marked improvement in conductance of cryogenics during a quench. A study of cryostat pressure as function of quench current and various relief mechanisms and geometries was undertaken. Data was presented by M. Kuchnir and K. Koepke. In parallel with these studies transfer ratio and harmonics as a function of magnet quench and heat cycle history were measured. A special study of subcooling dependence was also provided.

The format structure of this summary will be historical rather than topical in order to make transparent what was done to the magnets and when.

II. Tests on PCA148

Magnet PCA148 is an inner coil Ebonol, outer coil Staybrite type. Two stability tests were done on this magnet; one involving quenches with about 100-120 KJ dumped into the magnet per quench, the other involving warmup-cooldown cycles which effectively are more violent to the structure of the magnet although they occur much more slowly.

A full set of measurements, consisting of A.C. loss, transfer function vs. Z, D.C. harmonics and A.C. harmonics at three longitudinal positions was taken. This initial data served as a reference for subsequent measurements. Since normally magnets are trained in about a dozen quenches, or less, submitting this magnet to 20 additional quenches served as the basis of a check on whether quenches have any effect on the magnet's structure. Another full set of data was taken at this time. No changes were observed to the accuracy of the measurements, in any of the measured quantities.

An additional 50 quenches at high current (approaching or exceeding 4400A) were effected. Again subsequent measurements did not indicate any changes, therefore a further additional 60 quenches were produced (all quenches for this magnet were due to high ramp rate, Doubler rate - 200 A/S - or higher). This fourth set of data again was not substantively different from any of the previous.

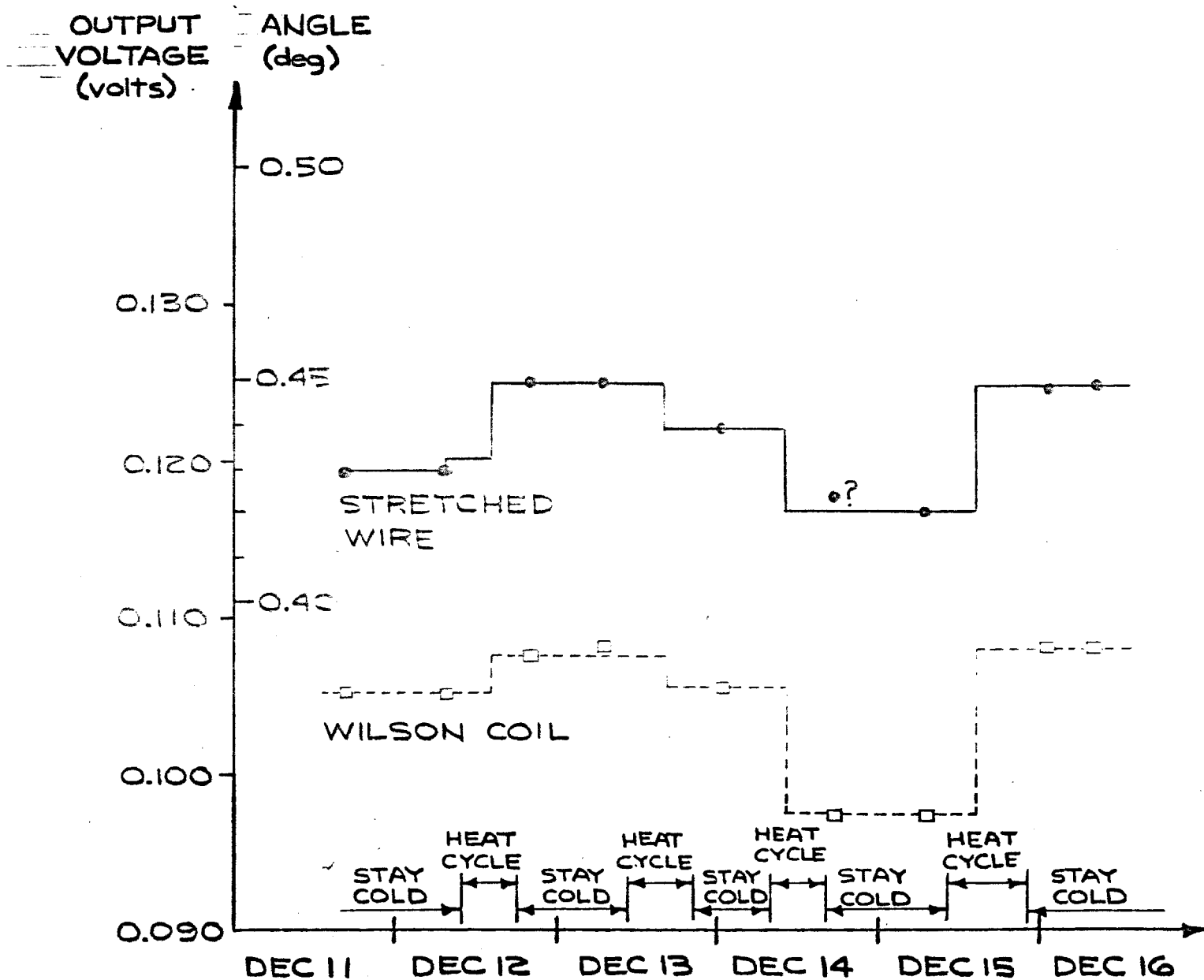
At this time we decided to proceed with warm-up cooldown cycles on magnet PCA148 - on as rapid a transition basis, as the refrigeration system could handle. Two of these cycles were run with subsequent measurements each. No variation on the initial data was observed.

As part of the previous tests interspersed with quenches we ran some data on the magnetic plane rotation. These data did indicate

Fixed Wire Measurement

MAGNET : PCA 148

BODY FIELD AT 3000A



Fixed Wire Measurement

-2b-

MAGNET: PCA 148

- 500A
- 1000A
- + 2000A
- x 3000A
- 4000A

Volts/kA
($1 \text{ m} \pm 0.016$)

Stretched Wire

WARMUP - COOLDOWN

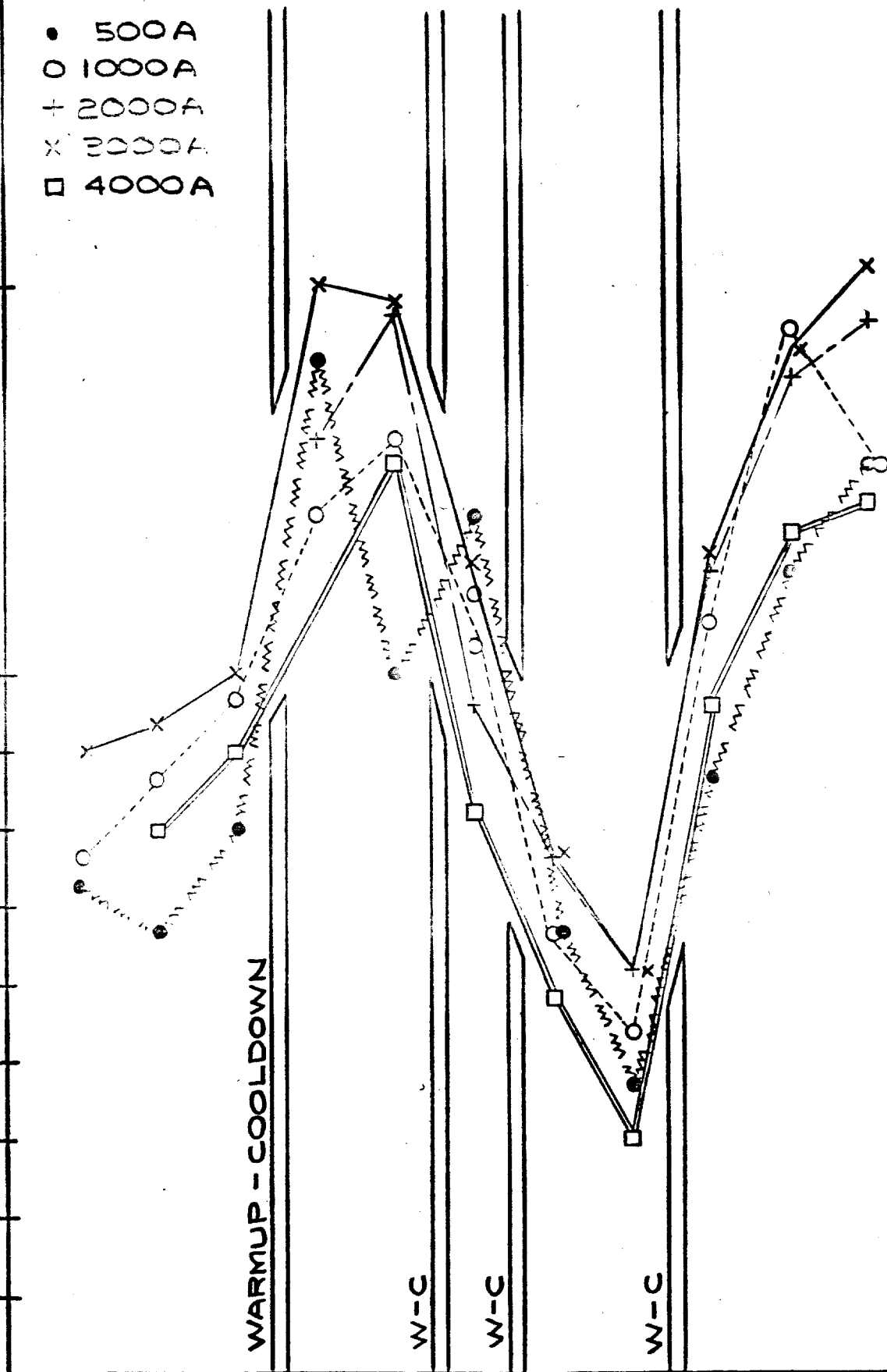
W-C

W-C

W-C

(I 13 I I) (II 11 II) (III) (IV 12 IV) (V 1.2 V 7 V) (VI
HRS GLUE HRS HRS HRS)

Cycles

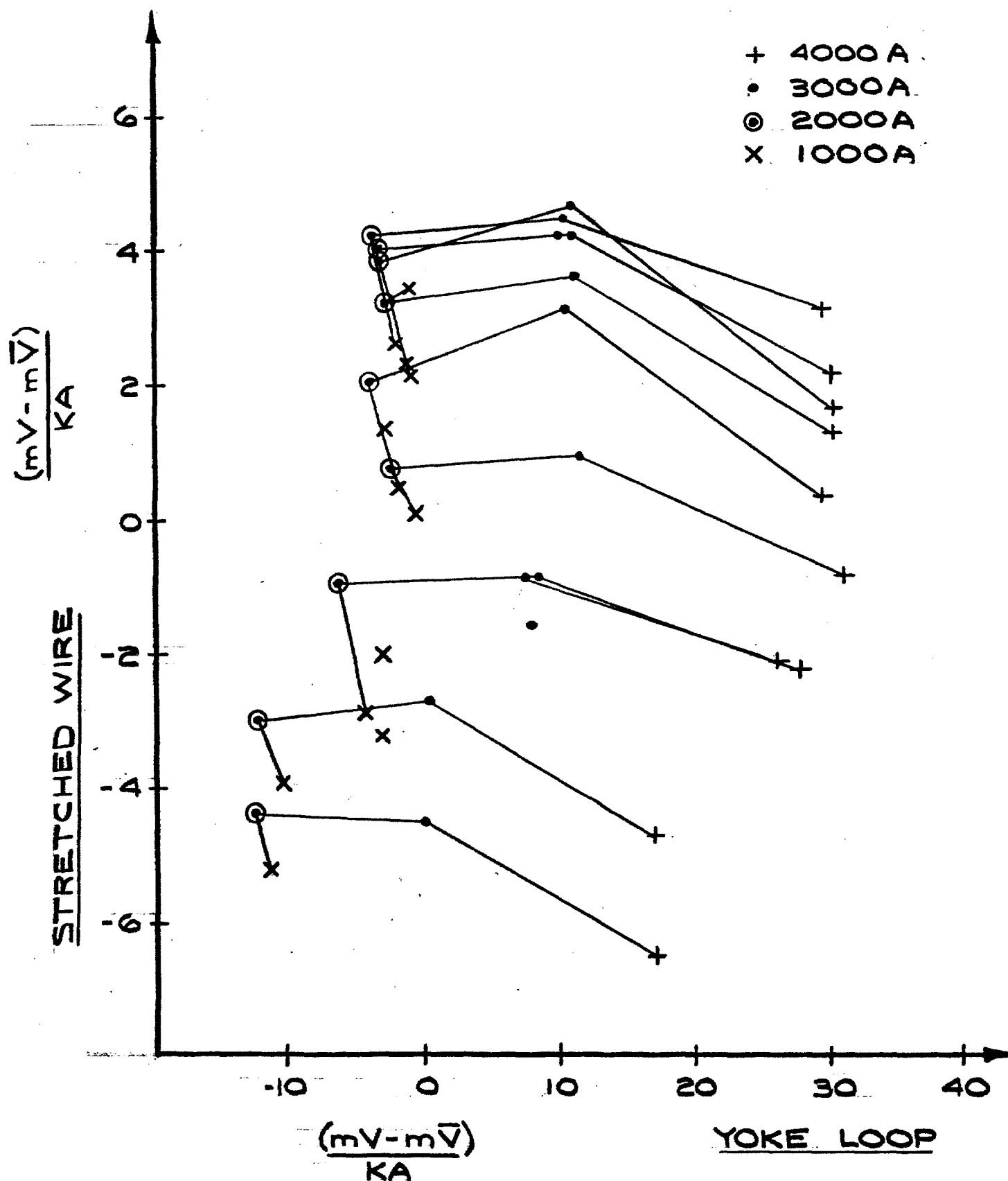


Stretched Wire vs. Yoke Loop

-2c-

MAGNET: PCA 148

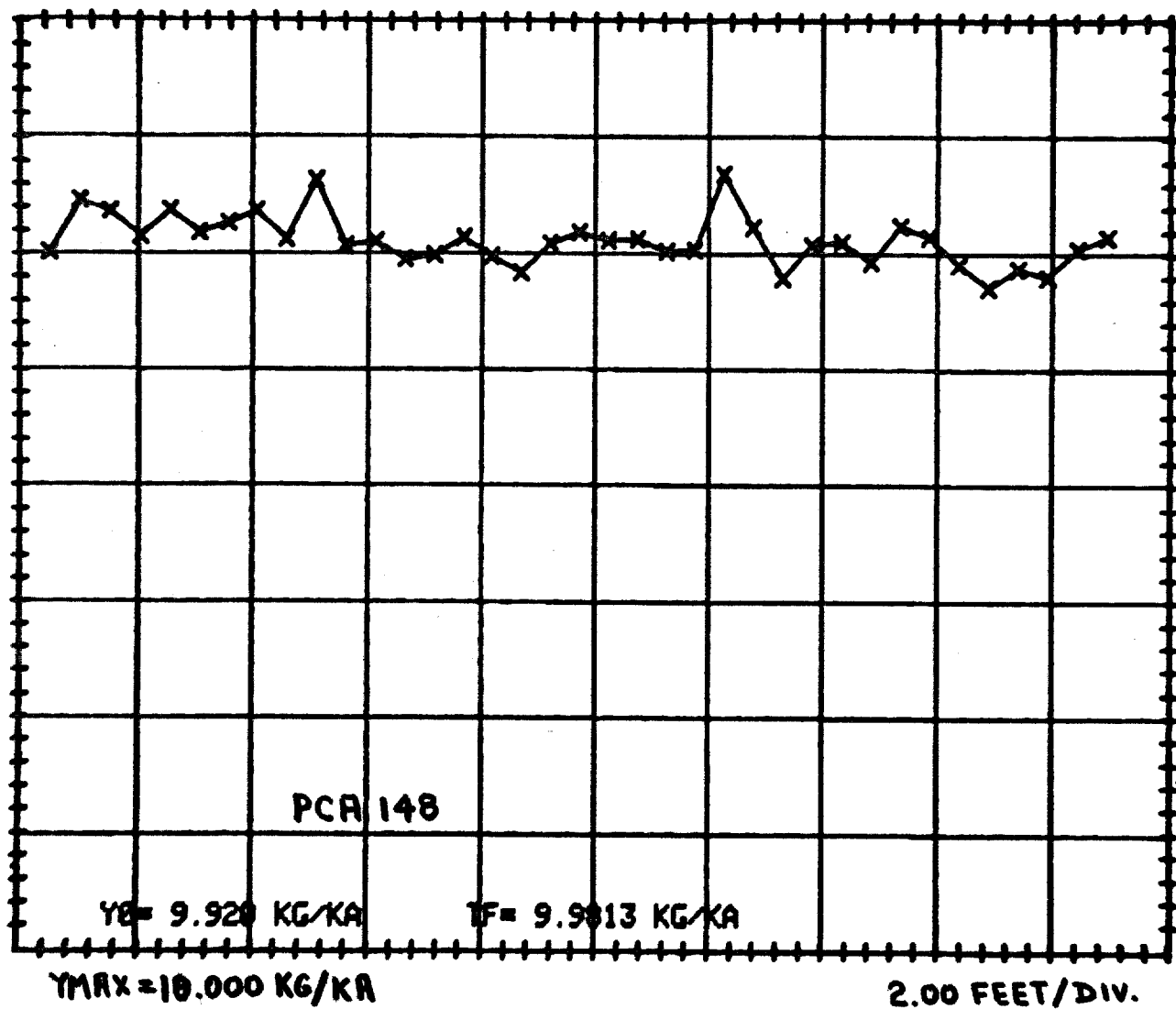
DATE: DEC 17, 1978



quite a few random changes amounting to as much as 15 mrad. We should point out promptly that these magnetic plane measurements involve a stretched wire loop about 30 feet long through the magnet in the set up of this loop for each set of data. Since we were measuring harmonic data inside the magnet bore it was necessary to break the loop after every set of data in order to insert the harmonic probe. This arrangement was particularly unfortunate since at this time the loop rotational directional is not directly measured but is inferred by a right angle measurement. We decided that the procedure was not proper and went on to a different schedule: measure only the magnetic plane and leave the wire loop in place. To make sure conditions stayed the same, we even glued the wire supports and wire, and welded the magnet to the measurement stand. Following a careful procedure of monitoring the magnet lamination plane, we acquired signals on the magnet bore wire loop (this involves inducing a voltage in the loop by means of ramping the magnet up and down). We also took data in a very similar manner by means of the wire loop stretched out inside the magnet laminations.

About one dozen sets of data were acquired this way. Two sets of data were generally taken between the warmup-cooldown phases. By means of this method we observed over all six cycles as much as $1/2$ mrad rotation of the magnetic plane and have good credibility of the data at the level of .1 mrad as indicated by complementary measurements between heat cycles.

It should be noted that this measurement on the direction of the magnetic plane is particularly difficult - the level of precision required being one tenth of one milliradian or better. We could claim to have achieved such a measurement accuracy in the sense that was



NMR T.F.

**** SUMMARY DATA ****

DATE: 15-NOV-78 MAGNET: PCA148 RUN: 6
 CURRENT: 4003. AMPERES
 CENTER DOWNSTREAM

POLE	ANGLE		NORMAL		SKEW		FFTB		FFTA
2	0.0000E 00		0.3995E 05		0.0000E 00		0.1000E 01		0.0000E 00
4	-0.6089E 02		0.1408E 01		0.2529E 01		0.3525E-04		0.6329E-04
6	0.7229E 01		0.6752E 01		-0.8564E 00		0.1690E-03		-0.2143E-04
8	0.7675E 02		0.3058E 00		-0.1299E 01		0.7653E-05		-0.3251E-04
10	0.3826E 01		0.3491E 00		-0.2335E-01		0.8736E-05		-0.5844E-06
12	0.8077E 02		0.3249E-01		-0.1999E 00		0.8131E-06		-0.5003E-05
14	-0.2379E 01		0.1483E 00		0.6161E-02		0.3712E-05		0.1542E-06
16	-0.9299E 02		-0.3791E-02		0.7263E-01		-0.9488E-07		0.1818E-05
18	0.1779E 03		-0.3492E-01		-0.1293E-02		-0.8741E-06		-0.3235E-07
20	0.8187E 02		0.5415E-03		-0.3791E-02		0.1355E-07		-0.9488E-07
22	-0.2456E 01		0.1882E-02		0.7727E-04		0.4510E-07		0.1934E-08
24	-0.1061E 03		-0.4577E-04		0.1584E-03		-0.1146E-08		0.3963E-08
26	0.1736E 03		-0.6742E-04		-0.7617E-05		-0.1688E-08		-0.1906E-09
28	-0.3824E 01		0.2449E-05		0.1637E-06		0.6129E-10		0.4897E-11
30	-0.1242E 03		-0.2609E-06		0.3845E-06		-0.6530E-11		0.9623E-11

DO YOU WANT TO ACCEPT RUN? (Y OR N): Y

ARE YOU FINISHED TAKING DATA? (Y OR N): N

indicated above, however the absolute angle is still an unsolved problem. Further refining of the hardware and electronics, and careful training of personnel is ongoing.

We shall list here the level of precision of some of the more important quantities measured:

- a. a.c. loss - a few Joules in about 250J for a 2000A ramp with much less than .1J/(A/s).
 - a few Joules in 550J for 4000A ramp at 200 A/s.
- b. NMR
 - about one part in 50,000 or better at a level of 9.9812 for the transfer ratio (average); the variation on t.f. longitudinally is approximately .0030.

- c. D.C. harmonics - sample sextupole measured over three integral thirds of the magnet, two including ends.

End upstream	$-7 \times 10^{-5}/\text{cm}^2$
End downstream	$-7 \times 10^{-5}/\text{cm}^2$
Center	$+17 \times 10^{-5}/\text{cm}^2$

Note that the integral thru the magnet is very close to zero.

The error level is of the order of $10^{-5}/\text{cm}^2$ or less (uncertainty).

These above values are representative of data at 2000A.

- d. A.C. harmonics - sample sextupole - following

End upstream	$-7 \times 10^{-5}/\text{cm}^2$
End downstream	$-7 \times 10^{-5}/\text{cm}^2$
Center	$+17 \times 10^{-5}/\text{cm}^2$
Uncertainty	$< 10^{-5}/\text{cm}^2$

All data (and much more than above listed) has been processed and is stored in the PDP-10 computer.

III. Tests on RDA101

This magnet's coils (both inner and outer) are Staybrite.

Throughout the measurement period for this magnet about 100 quenches were performed interspersed with data taking and also some warmup-cooldown cycling.

One of the most important measurement quantities was the internal cryostat pressure during a full current quench up to 4500-4600A. For this purpose the beam line was enlarged and sharp bends in it rounded. A system of various Ross and/or Anderson Greenwood pneumatic valves with large effective apertures was used to substantially reduce the pressure built up during the quenches (equivalent 1100 GeV highest current). The data has been compiled by K. Koepke and M. Kuchnir and has been already publicized while hardware is being specified for Tunnel operation.

During these quenches an enhanced mode of dumping most of the field stored energy into the magnet was operative. A heater (strip along coil) was fired at the moment an incipient quench was detected. This heater propagates the quench more effectively than a temperature unclamping or a rapid flux change do. No external dump resistor was used (save for the power buss network resistance $8\text{m}\Omega$). In this mode virtually all energy was dumped into the magnet, amounting to upwards of 450 KJ. The pressures generated (depending on exhaust valves and their geometry) were less than 120 psi, well within cryostat tolerance of 150 psi or more. The effective temperature of the coil during such quenches becomes 150-200°K. Thus these quenches are quite vigorous and much violence to the mechanical structure is being done.

Four sets of data interleaved with these "high energy" (dumped internally) quenches were taken. As in the case of PCA148 no noticeable changes were observed within the measurement uncertainties. These measurements consisted of a.c. loss, transfer ratio by means of NMR, harmonics (D.C. and A.C.). (No data on magnetic plane or integral field length was obtained because the only extant hardware was at the time rigidly fixed in the PCA148 measurement stand.)

The following are some sample data with similar error bars compared to PCA148 measurements:

- a. a.c. loss - 1300J at 200A/s for 4100A ramp.
300J extrapolated to 0A/s for 2000A ramp
with about 1.0J/(A/s).
- b. NMR - 9.9710 is transfer ratio (longitudinal average).
 $< 2 \times 10^{-4}$ uncertainty per measured location.
40 longitudinal positions measured thru magnet.
- c. D.C. harmonics - sample sextupole at 2000A
End upstream - $20 \times 10^{-5}/\text{cm}^2$
End downstream - $20 \times 10^{-5}/\text{cm}^2$
Center + $7 \times 10^{-5}/\text{cm}^2$
- d. A.C. harmonics - surprisingly sextupole has almost no
noticeable changes in this mode compared
to D.C. mode.
(Since this is a Staybrite coil there
might have been some variation.)
Normal data is taken at 50 A/sec.
We did however acquire some data at
Doubler ramp rates - 200 A/sec. (= about
50 GeV/sec).

I_{max} adjusted for 1ϕ temperature
vs. $\Delta P (\psi)$

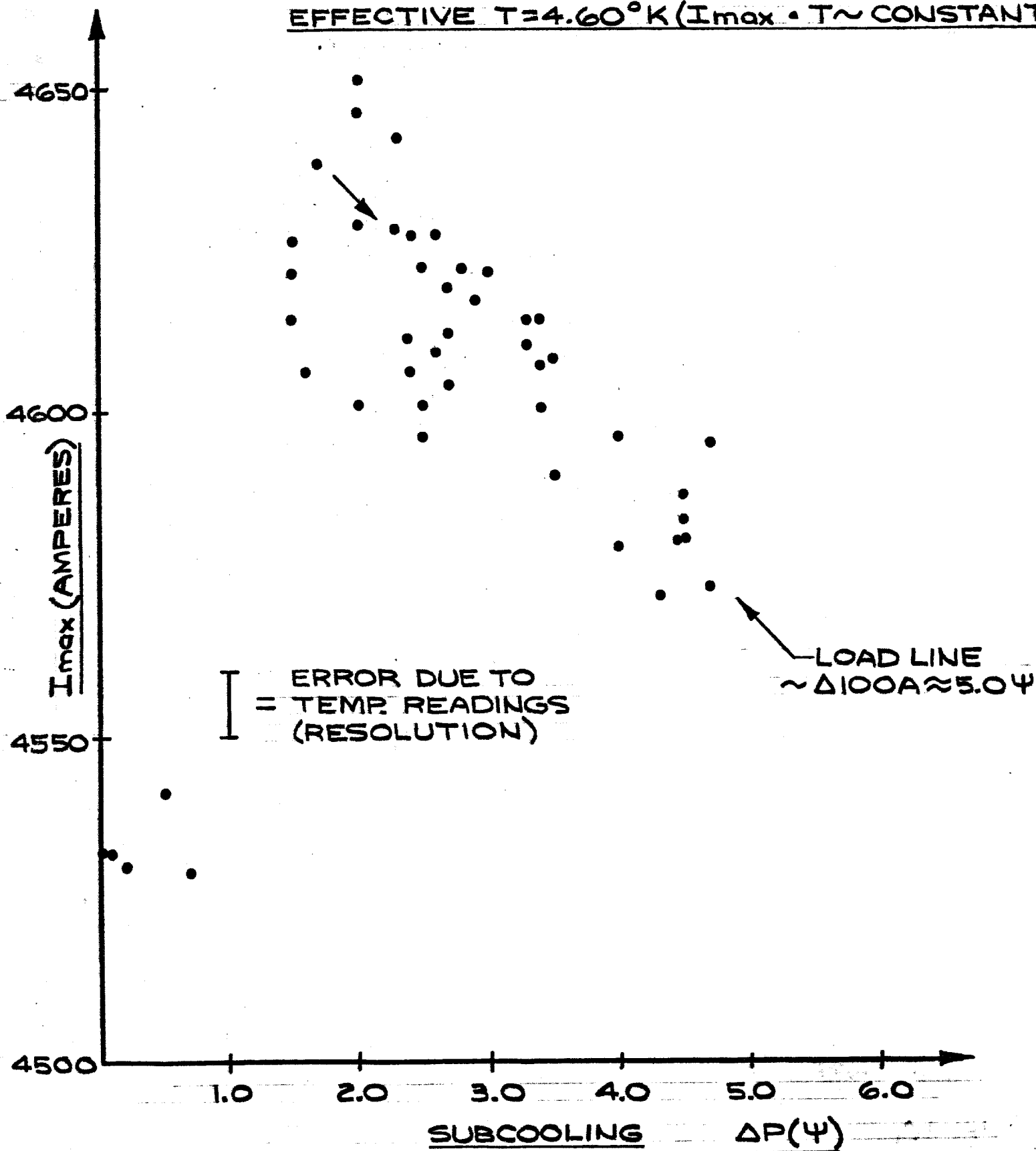
-6a-

MAGNET: RDA 101 (STAYBRITE)

DATE: DEC 17, 1978

RAMP RATE: 50A/SEC

EFFECTIVE $T = 4.60^\circ K (I_{max} \cdot T \sim \text{CONSTANT})$



I_{max} adjusted for Subcooling vs.

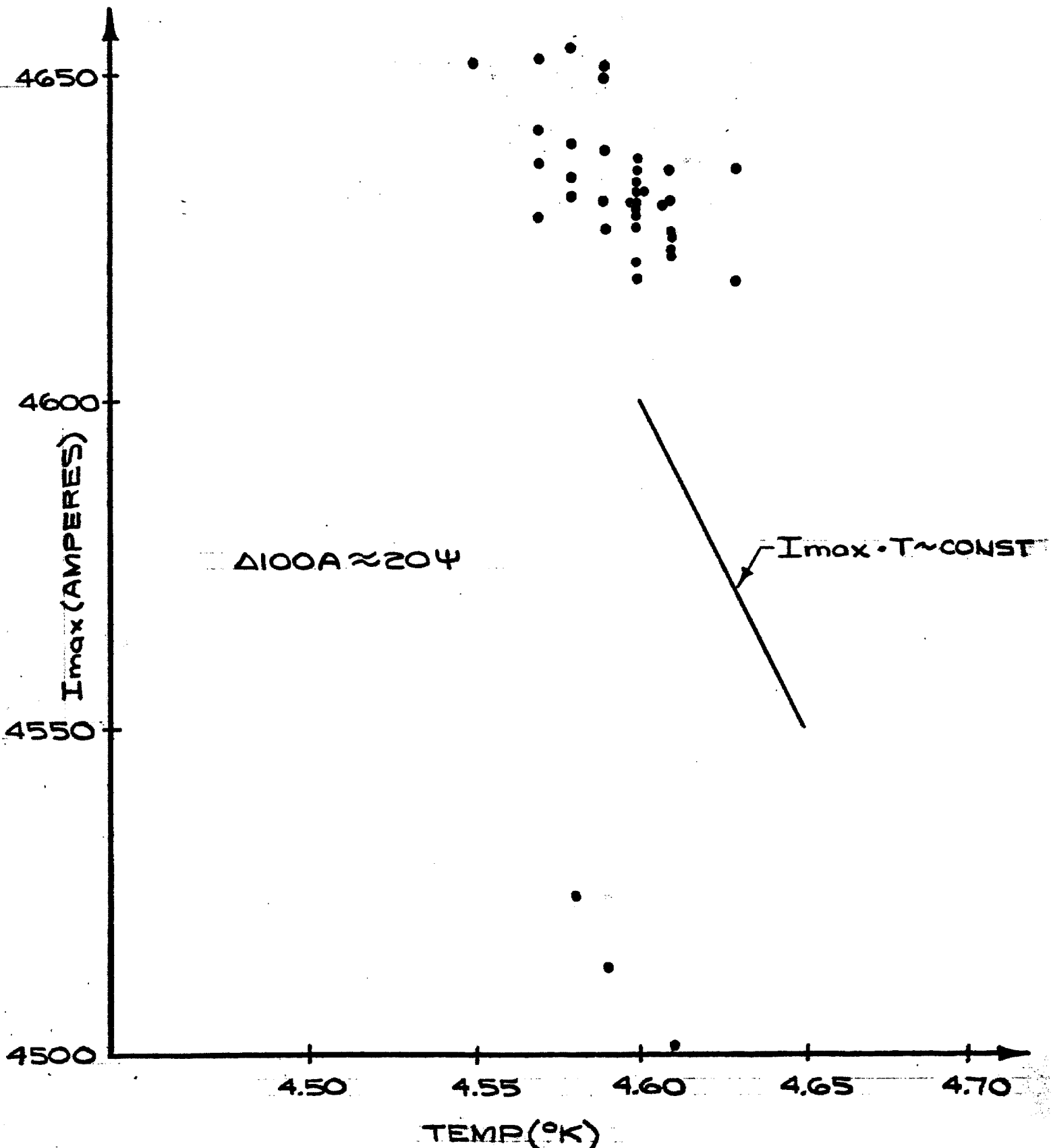
-6b-

$T_{in}(1\phi)$

MAGNET: RDA101 (STAYBRITE)

DATE: DEC. 17, 1978

RAMP RATE: 50A/SEC

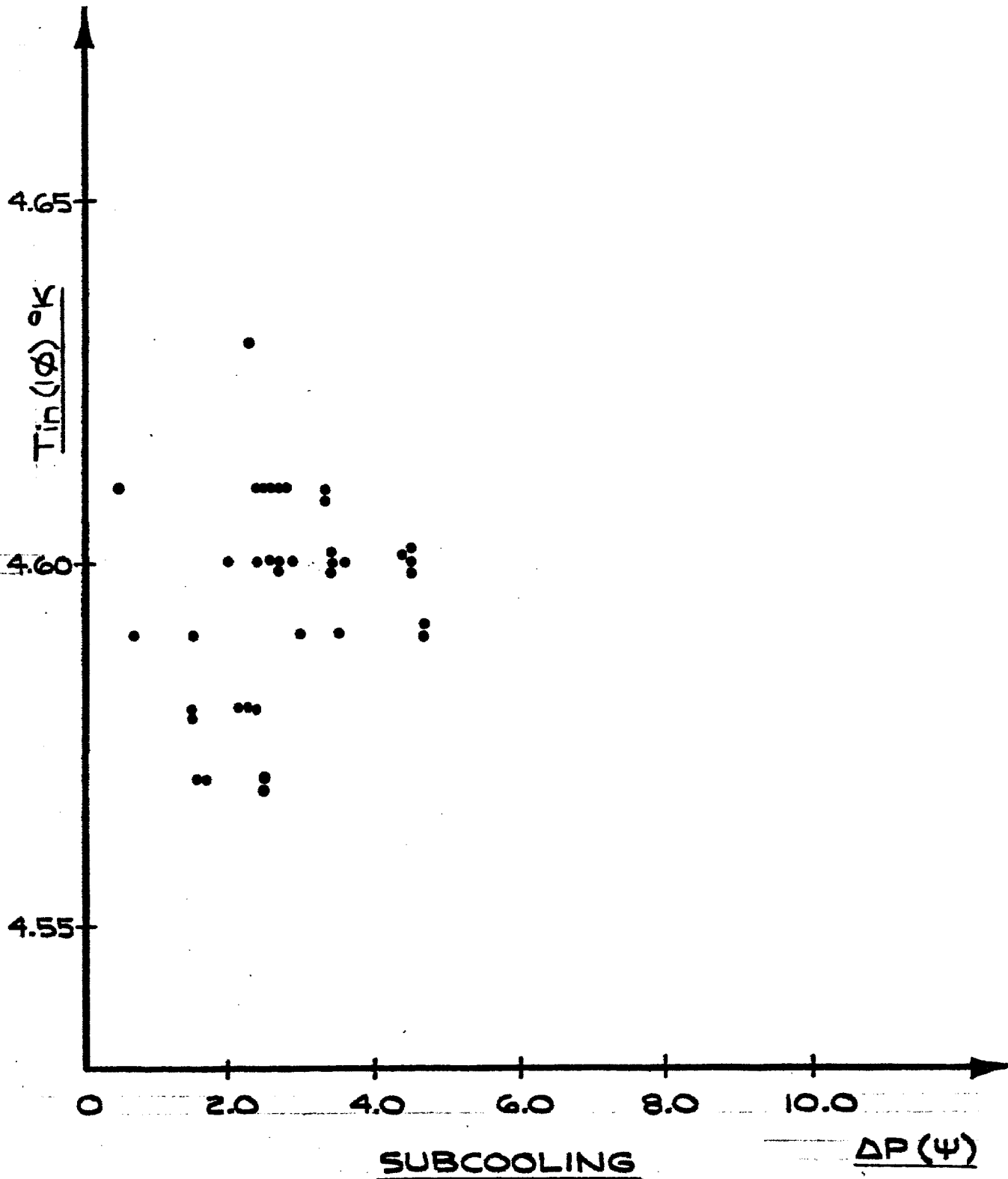


$T_{in}(\phi)$ vs. $\Delta P(\psi)$

MAGNET: RDA 101 (STAYBRITE)

DATE: DEC. 17, 1978

RAMP RATE: 50A/SEC.



Another intensive effort was made to measure the effects of subcooling level on the quench current. During this procedure the magnet reached 4658A before quenching (~ 1100 GeV equivalent).

Since this magnet is Staybrite we attempted to reduce the quenching tendency due to heating generated by \dot{I} (eddy currents) and ramped the magnet slowly (50A/sec).

Data was collected just prior to quench. The datum of most interest was the subcooling extent. Data over the range of 0 to 5 psi subcooling was obtained, although due to refrigerator requirements there is an effective break in continuity, based on liquid helium flow, at 1.5 psi subcooling.

An attempt to reduce the data (by means of $I_{\max} \cdot T_{10} \sim \text{constant.}$) to the same effective temperature and obtaining an effective load line was done. We found a peaking at about 2.0 psi subcooling with a derating factor of 20 A/psi subcooling beyond this point.

This data is preliminary and should be regarded as such. A more automated data acquisition system is being worked on presently and this system should couple successfully with heat load measurements.

IV. Conclusion

An extensive attempt has been made to determine whether operational and extra operational conditions and transitions have any effect on the Energy Doubler magnet structure by means of effecting detailed measurements on two types of magnet, a relatively recent magnet PCA148 - Ebonol inner coil - and an older magnet RDA101 - Staybrite both coils.

The measurements indicate very convincingly that to the extent that the magnets have been operated no observable changes are detected at the level of the uncertainties in the measured quantities and

these uncertainties are small and generally satisfactory (nevertheless various improvements are envisioned or being implemented now).

In the case of the magnetic plane rotation it might be interesting to measure a break-in period - if there is one. An early monitoring of the magnetic plane in a predetermined magnet is required.

We have indications to believe these particular two magnets will be dissected in various ways to determine whether any damage has occurred to the coil, cryostat and/or support system.

DG/nep